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Indian Standard
ELECTROTECHNICAL VOCABULARY
PART XII FERROMAGNETIC OXIDE MATERIALS

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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July 1967

Indian Standard
ELECTROTECHNICAL VOCABULARY
PART XII FERROMAGNETIC OXIDE MATERIALS

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Indian Standard
ELECTROTECHNICAL VOCABULARY
PART XII FERROMAGNETIC OXIDE MATERIALS

0. FOREWORD

0.1 This Indian Standard (Part XII) was adopted by the Indian Standards Institution on 19 November 1966, after the draft finalized by the Electrotechnical Standards Sectional Committee in consultation with the Piezo Electric and Ferromagnetic Materials Sectional Committee, had been approved by the Electrotechnical Division Council.

0.2 The electrotechnical vocabulary is being prepared in several parts each having one or more sections. Other parts so far published in this series are given on P. 23-24.

0.3 This part of the standard covers definitions of terms relating to ferromagnetic oxide materials used in telecommunication and electronic equipment. The materials covered in this standard are those which display ferromagnetic properties and consist primarily of oxides. This includes the class of materials usually known as ferrite.

0.4 Terms relating to magnetism are already covered by IS : 1885 (Part I)-1961*; however, for the sake of completeness and for ready understanding of other definitions, relevant terms on magnetism are also being repeated in this standard.

0.5 This standard is one of a series of Indian Standards on ferromagnetic oxide materials. Other standards which are under preparation relate to methods of measurements for ferromagnetic materials, dimensions of ferromagnetic materials, aerial rods and IF cores, cores for data storage devices (memory cores), etc.

0.6 Assistance has been derived from IEC Pub 125 (1961) 'General classification of ferromagnetic oxide materials and definitions of terms' issued by International Electrotechnical Commission in the preparation of this standard.

1. SCOPE

1.1 This standard (Part XII) lays down terms and definitions for use in the field of ferromagnetic materials and more specially relating to ferromagnetic oxide parts and materials. It does not include special terms such as those for the voltage response of data storage cores.

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*Electrotechnical vocabulary: Part I Fundamental definitions.

NOTE 1 — When applying a term to a specific part of ferromagnetic oxide, it may be necessary to limit the meaning of that term in a more precise manner than has been laid down in this standard. Such limitations have been indicated in the relevant clauses by the addition of the expression 'under stated conditions'.

NOTE 2 — The equations included in this part of the standard and given in MKSA units are also valid for the CGS system when μ_0 is set equal to 1 gauss/oersted.

2. GENERAL

2.1 Ferromagnetism — A phenomenon in which the magnetic moments of neighbouring atoms over certain regions are aligned approximately in the same direction due to mutual interaction.

2.2 Ferromagnetic Material — A material in which the predominant magnetic phenomenon is ferromagnetism. The atoms or ions have magnetic moments which, over certain regions (domains), are aligned approximately in the same direction even in the absence of an externally applied magnetic field. When such a field is applied, the resultant moments of domains tend to align and the material exhibits considerable permeability. The degree of alignment within a domain decreases with increasing temperature.

NOTE — Reference may be made to Appendix A for the material classification made on functional basis.

2.3 Ferrimagnetism — A phenomenon in which, in the absence of an externally applied magnetic field, the magnetic moments of neighbouring atoms or ions over certain regions are held due to mutual interaction in a partially cancelling arrangement such that there is a resultant magnetic moment.

2.4 Ferrimagnetic Material — A material in which the predominant magnetic phenomenon is ferrimagnetism. The atoms or ions have magnetic moments which, over certain regions (domains), are held in a partially cancelling arrangement such that there is a resultant magnetic moment even in the absence of an externally applied magnetic field. When such a field is applied the resultant moments of the domains tend to align so that the material may exhibit considerable permeability. The permeability is dependent on the temperature.

3. PERMEABILITY

3.1 Material Constants

3.1.1 *Absolute Permeability* — The magnetic flux density divided by the magnetic field strength [*see also* **10.1** of IS : 1885 (Part I)-1961*].

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*Electrotechnical vocabulary: Part I Fundamental definitions.

3.1.2 *Relative Permeability* — The ratio of the absolute permeability of a substance or medium to that of a vacuum [*see also* **10.41** of IS : 1885 (Part I)-1961*].

NOTE — The permeabilities mentioned hereafter can be used as absolute and relative permeabilities. By deleting μ_0 in the following definitions, the permeability becomes absolute.

3.1.3 *Tensor Permeability* — Under stated conditions, the quotient of the space vectors representing induction and field strength inside the material.

NOTE 1 — In the presence of a second active field, the tensor permeability becomes a second order tensor.

NOTE 2 — If the fields are time dependent, the resulting tensor components may be complex since they also represent the losses in the medium.

3.1.4 *Polder's Tensor Permeability* — For a specific model with time dependent fields, the second order tensor permeability in the case when the second magnetic field is a static field which saturates the material.

3.1.5 *Complex Permeability* — Under stated conditions, the complex quotient of the vectors representing induction and field strength inside the material; one of these vectors varying sinusoidally with time, and that component being chosen from the other vector, which varies sinusoidally at the same frequency.

The space vectors characterising field strength and induction are assumed to be parallel:

$$\bar{\mu} = \mu'_s - j\,\mu''_s = \frac{1}{\mu_0}\,\frac{\bar{B}}{\bar{H}} \text{ or}$$

$$\frac{1}{\bar{\mu}} = \frac{1}{\mu'_p} - \frac{1}{j\mu''_p} = \mu_0\,\frac{\bar{H}}{\bar{B}}$$

where

$\bar{\mu}$ = complex permeability;

μ'_s = real component of the complex permeability expressed in series terms;

μ''_s = absolute value of imaginary component of the complex permeability expressed in series terms;

μ'_p = real component of the complex permeability expressed in parallel terms;

μ''_p = absolute value of the imaginary component of the complex permeability expressed in parallel terms;

μ_0 = absolute permeability of vacuum in volt seconds per ampere metre;

$\bar{B}$ = the complex field strength, in amperes per metre;

$\bar{H}$ = the complex induction, in webers per square metre; and

j = $\sqrt{-1}$.

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*Electrotechnical vocabulary: Part I Fundamental definitions.

NOTE 1 — When the field strength is sufficiently small to ensure that the complex permeability is independent of the field strength, the moduli of both vectors will have the same wave shape.

NOTE 2 — For the complex permeability expressed in series terms, *see* **3.2.4**. For the complex permeability expressed in parallel terms, *see* **3.2.5**.

3.1.6 *Initial Permeability* — Under stated conditions, the limiting value of permeability of a ferromagnetic body at the origin of the curve of first magnetization [*see also* **10.12** of IS : 1885 (Part I)-1961*].

$$\mu_i = \frac{1}{\mu_0} \lim_{H \to 0} \frac{B}{H}$$

where

μ_i = relative initial permeability;

μ_0 = absolute permeability of vacuum in volt seconds per ampere metre;

H = parameter characterizing the amplitude of the alternating field strength (for example, peak value) in amperes per metre; and

B = corresponding parameter for the induction (for example, peak value) in webers per square metre.

3.1.7 *Amplitude Permeability* — Under stated conditions, the permeability at a stated value of the field strength or of the induction, the field strength varying periodically with time and no static magnetic field being present.

$$\mu_a = \frac{1}{\mu_0} \frac{B}{H}$$

where

μ_a = relative amplitude permeability,

μ_0 = absolute permeability of vacuum in volt seconds per ampere metre,

H = parameter characterizing the amplitude of the alternating field strength in amperes per metre, and

B = corresponding parameter for the induction in webers per square metre.

NOTE — In particular, the wave shape of the field strength or induction and the parameters characterizing the field strength and the induction respectively should be stated. In this latter respect, two amplitude permeabilities are commonly used, namely:

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*Electrotechnical vocabulary: Part I Fundamental definitions.

a) Amplitude permeability of rms values:

$$\mu_{ae} = \frac{1}{\mu_0}\,\frac{B_e}{H_e}, \text{ where } B_e \text{ and } H_e \text{ are rms values.}$$

b) Amplitude permeability of peak values:

$$\mu_{ap} = \frac{1}{\mu_0}\,\frac{B_{max}}{H_{max}}, \text{ where } B_{max} \text{ and } H_{max} \text{ are peak values.}$$

3.1.7.1 *Permeability rise factor* — The relative change of the amplitude permeability between two specified values of the sinusoidal field strength.

$$\delta = \frac{\mu_{a2} - \mu_{a1}}{\mu_{a1}\,(H_2 - H_1)}$$

where

δ = permeability rise factor between H_1 and H_2,

μ_{a2} and μ_{a1} = amplitude permeabilities at sinusoidal field strength measured at H_2 and H_1 respectively, and

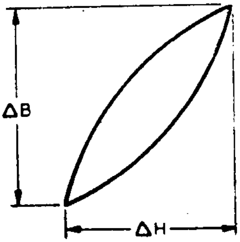
H_2 and H_1 = parameter characterizing the amplitude of the sinusoidal field strength in amperes per metre ($H_2 > H_1$).

NOTE — The same considerations as given in Note under **3.1.7** apply here.

3.1.7.2 *Maximum amplitude permeability* — The maximum value of the amplitude permeability as a function of the field strength or of the induction.

NOTE — The same considerations as given in Note under **3.1.7** apply here.

3.1.8 *Incremental Permeability* — Under stated conditions, the permeability at alternating magnetic field and in the presence of a static magnetic field (*see* figure below):



$$\mu_\Delta = \frac{1}{\mu_0}\cdot\frac{\Delta B}{\Delta H}$$

where

μ_Δ = relative incremental permeability,

μ_0 = absolute permeability of vacuum in volt seconds per ampere metre,

$\triangle H$ = parameter characterizing the peak-to-peak value of the incremental field strength in amperes per metre, and

$\triangle B$ = corresponding parameter for the induction in webers per square metre.

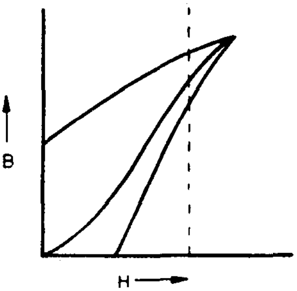
NOTE — In particular, the following points should be stated:

a) The relative directions of the static and alternating fields,

b) The way of attaining the static field strength (*see* figure below), and

c) The amplitude of the alternating field strength.

In general, the alternating field strength will be approximately sinusoidal.



3.1.9 *Reversible Permeability* — The limiting value of the incremental permeability when the alternating field strength approaches zero.

$$\mu_{rev} = \lim_{\triangle H \to 0} \mu_{\triangle}$$

NOTE — At present, this term is used for permanent magnets to indicate the permeability at a given state of magnetization (point on the *B-H* curve in the second quadrant). This practice is deprecated.

3.1.10 *Differential Permeability* — The rate of change of the magnetization or of the induction with respect to the magnetic field [*see also* **10.9** of IS : 1885 (Part I)-1961*].

$$\mu_{diff} = \frac{1}{\mu_0} \frac{dB}{dH}$$

where

μ_{diff} = (relative) differential permeability,

μ_0 = absolute permeability of vacuum in volt second per ampere metre,

dB = corresponding change of induction in the considered point of the B-H curve in webers per square metre, and

dH = infinitely small change of field strength in ampere per metre.

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*Electrotechnical vocabulary: Part I Fundamental definitions.

3.2 Measurement and Calculation of Material Constants on Components

3.2.1 *Toroidal Permeability* — Under stated conditions, the intrinsic relative permeability of a material determined by making measurements on a toroid of the material. This is usually calculated from measurements, made on a coil wound on the toroid in which stray fields have been minimized or can be neglected using the approximate expression:

$$\mu_{tor}-1=\frac{1}{\mu_0}\,\frac{L-L'}{N^2}\,\frac{l}{A}$$

where

μ_{tor} = (relative) toroidal permeability,

μ_0 = absolute permeability of vacuum in volt seconds per ampere metre,

L = self-inductance in henrys of the coil on the core,

L' = self-inductance in henrys of the coil without core,

N = number of turns of the coil,

l = magnetic length in metres measured along the axis circle of the toroid (*see* Note 2), and

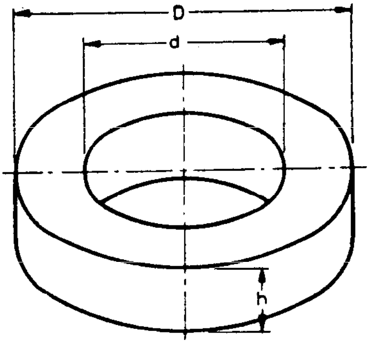
A = cross-sectional area of the toroid in square metres.

NOTE 1 — In the case when L is given in henrys, l in centimetres and A in square centimetres, the following equation applies:

$$\mu_{tor}-1=\frac{L-L'}{0{\cdot}4\pi N^2}\,\frac{l}{A}\,10^8$$

NOTE 2 — When a ring with rectangular cross-section is used (*see* Figure below), the following exact formula is valid:

$$\mu_{tor}-1=\frac{1}{\mu_0}\,\frac{L-L'}{N^2}\,\frac{2\pi}{h\log_e\dfrac{D}{d}}$$



In case when L is given in henrys, l in centimetres and A in square centimetres, the following equation applies:

$$\mu_{tor}-1=\frac{L-L'}{0\cdot2\,N^2}\,\frac{1}{h\log_e\frac{D}{d}}\,10^8$$

NOTE 3 — The toroidal permeability measurements can be made corresponding to any of the permeabilities defined in **3.1.6** to **3.1.10** and may be indicated by using the terms toroidal initial permeability, toroidal amplitude permeability, etc.

3.2.2 *Effective Permeability* — Under stated conditions for a component built-up of different materials, the magnetic stray flux being negligible, the resulting permeability, defined as the permeability of a hypothetical homogeneous material having the same shape, dimensions and total reluctance.

Two equations are of interest:

$$\text{a)}\ \mu_e=\frac{1}{\mu_0}\,\frac{L}{N^2}\,\Sigma\,\frac{l}{A}\,,\ \text{and}$$

$$\text{b)}\ \mu_e=\frac{\Sigma\,\frac{l}{A}}{\Sigma\,\frac{l}{\mu A}}$$

where

μ_e = relative effective permeability,

μ_0 = absolute permeability of vacuum in volt seconds per ampere metre,

L = self-inductance in henrys of the measuring coil placed on the core,

N = number of turns of the measuring coil,

l = magnetic length in metres of each part of constant cross-sectional area and of the same material,

A = cross-sectional area in square metres of each part, and

μ = permeability of each material.

NOTE 1 — The effective permeability is used for the calculation of temperature coefficient and losses, such as tan δ/μ and hysteresis losses.

NOTE 2 — The formulæ are especially used for cores with an air gap. The first formula is used for measurements and the second one for calculations in those cases where dimensions of the core are given.

3.2.3 *Apparent Permeability* — Under stated conditions, the relative permeability measured on a core with the aid of a measuring coil; the parameter characterizing the induction in the core being the self-inductance of the measuring coil when placed on the core and the parameter characterizing the field strength, applied to the core, being the self-inductance of the measuring coil when placed in air.

$$\mu_{app} = \frac{L}{L'}$$

where

μ_{app} = apparent permeability,
L = self-inductance in henrys of the measuring coil with the core of magnetic material, and
L' = self-inductance in henrys of the measuring coil without core.

NOTE 1 — This quantity is purely arbitrary and is dependent on the form of core and coil, the position of the coil on the core, etc.

NOTE 2 — The effective permeability equals the apparent permeability only when the distribution of the magnetic field in the coil with and without core is identical. This may be the case for toroidal coils.

3.2.4 *Complex Permeability Expressed in Series Terms* — Under stated conditions, the complex relative permeability as measured on a core with the aid of a coil, the parameter characterizing the induction in the core being the impedance of the coil when placed on the core, expressed as a series connection of reactance and resistance and the parameter characterizing the field strength being the self-inductive reactance this coil would have were it placed on a core of the same dimensions but with unit relative permeability (the distribution of the magnetic field being identical in both cases). The impedance of the coil should be entirely determined by the magnetic properties (negligible copper losses, etc).

$$\begin{aligned} \bar{\mu} &= \mu'_s - j\,\mu''_s \\ \bar{Z} &= j\,\omega\,L_s + R_s = j\,\omega\,\bar{\mu}\,L_0 \\ L_s &= \mu'_s\,L_0 \\ R_s &= \omega\,\mu''_s\,L_0 \end{aligned}$$

where

$\bar{\mu}$ = complex permeability,
μ'_s = real component of the complex permeability expressed in series terms,
μ''_s = absolute value of imaginary component of the complex permeability expressed in series terms,
j = $\sqrt{-1}$,
$\bar{Z}$ = complex impedance in ohms,
ω = 2π × frequency in cycles per second,
L_s = self-inductance of the coil in henrys with a core of magnetic material (calculated as series inductance),
R_s = resistance of the coil in ohms with a core of magnetic material (calculated as series resistance), and
L_0 = self-inductance of the coil in henrys with a core having a permeability equal to that of vacuum.

3.2.5 *Complex Permeability Expressed in Parallel Terms* — Under stated conditions, the complex relative permeability as measured on a core with the aid of a coil; the parameter characterizing the induction being the impedance of the coil when placed on the core expressed as a parallel connection of reactance and resistance, and the parameter characterizing the field strength being the self-inductive reactance this coil would have were it placed on a core of the same dimensions but with unit relative permeability (the distribution of the magnetic field being identical in both cases). The impedance of the coil should be entirely determined by the magnetic properties (negligible copper losses, etc).

$$\frac{1}{\bar{\mu}} = \frac{1}{\mu'_p} - \frac{1}{j\mu''_p}$$

$$\frac{1}{\bar{Z}} = \frac{1}{j\omega L_p} + \frac{1}{R_p} = \frac{1}{j\omega\bar{\mu}L_0}$$

where

$\bar{\mu}$ = complex permeability,

μ'_p = real component of the complex permeability expressed in parallel terms,

μ''_p = absolute value of the imaginary component of the complex permeability expressed in parallel terms,

j = $\sqrt{-1}$,

$\bar{Z}$ = complex impedance in ohms,

ω = 2π × frequency in cycles per second,

L_p = self-inductance of the coil in henrys with a core of magnetic material (calculated as parallel inductance),

R_p = resistance of the coil in ohms with a core of magnetic material (calculated as parallel resistance), and

L_0 = self-inductance of the coil in henrys with a core having a permeability equal to that of vacuum.

NOTE 1 — The relation between μ'_s and μ'_p is given by:

$$\mu'_p = \mu'_s\,(1+\tan^2\delta)$$

$$\tan\delta = \frac{\mu''_s}{\mu'_s} = \frac{\mu'_p}{\mu''_p}$$

For cores where tan δ is smaller than 0·1, the real parts of the complex permeabilities are practically equal. This may not be the case for transformer cores where tan δ may exceed 1.

NOTE 2 — The real parts of the complex permeability correspond to the relative permeability and the imaginary parts correspond to magnetic losses.

3.2.6 *Tensor Permeability* — Under consideration.

3.2.7 *Polder's Tensor Permeability* — Under consideration.

3.2.8 *Scalar Permeability for Circularly Polarized Fields* — Under consideration.

3.2.9 *Effective Scalar Permeability for Plane Waves* — Under consideration.

3.3 Practical Quantities Related to Permeability for Coils on Cores

3.3.1 *Turns Factor* — Under stated conditions, the number of turns that a coil of specified shape and dimensions placed on the core in a given position should have to obtain a given unit of self-inductance.

When measured with a measuring coil of the specified shape and dimensions and placed in the same position, it is derived from :

$$\alpha = \frac{N}{\sqrt{L}}$$

where

α = turns factor,
N = number of turns of the measuring coil, and
L = self-inductance in henrys of the measuring coil placed on the core.

3.3.2 *Inductance Factor* — Under stated conditions, the self-inductance that a coil of specified shape and dimensions placed on the core in a given position should have, if it consisted of one turn.

$$A_L = \frac{L}{N^2}$$

where

A_L = inductance factor,
L = self-inductance of the coil in henrys, and
N = number of turns of the coil.

4. LOSSES

4.1 General Definitions

4.1.1 *Total Losses of a Ferromagnetic Part* — Under stated conditions, the power absorbed by a body of ferromagnetic material and dissipated as heat when that body is subjected to a time varying magnetic field.

4.1.1.1 *Losses* — The difference between input and the useful output of a system (energy, power, quantity of electricity, etc) [*see also* **5.3** of IS : 1885 (Part I)-1961*].

4.1.2 *Eddy Current Losses* — The losses caused by the eddy currents in a ferromagnetic part.

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*Electrotechnical vocabulary: Part I Fundamental definitions.

4.1.2.1 *Eddy* (*Foucault*) *currents* — The currents induced in the interior of conducting masses by variations of the magnetic flux [*see also* **8.14** of IS : 1885 (Part I)-1961*].

4.1.3 *Hysteresis Losses* — The losses caused by the magnetic hysteresis in a ferromagnetic part, when the magnetic field varies with time.

4.1.3.1 *Magnetic hysteresis* — The phenomenon by which the magnetization of ferromagnetic bodies depends, not only on the actual value of the field, but also on the previous magnetic state [*see also* **10.21** of IS : 1885 (Part I)-1961*].

4.1.4 *Residual Losses* — The difference between the total losses (*see* **4.1.1**) and the sum of the eddy current and hysteresis losses.

4.1.5 *Gyromagnetic Resonance Losses* — The losses associated with the occurrence of gyromagnetic resonance.

NOTE — Details are under consideration.

4.2 Expression of Losses

4.2.1 *Tangent of Loss Angle* — Under stated conditions, the quotient of the absolute value of the imaginary part and the real part of the complex permeability expressed in series terms. Alternatively, the quotient of the real part and the absolute value of the imaginary part of the complex permeability expressed in parallel terms.

$$\tan\delta = \frac{\mu''_s}{\mu'_s} = \frac{\mu'_p}{\mu''_p}$$

where

$\tan\delta$ = tangent of loss angle,

μ'_s = real component of the complex permeability expressed in series terms,

μ''_s = absolute value of imaginary component of the complex permeability expressed in series terms,

μ'_p = real component of the complex permeability expressed in parallel terms, and

μ''_p = absolute value of the imaginary component of the complex permeability expressed in parallel terms.

NOTE — The tangent of loss angle can be split in components corresponding to the losses defined in **4.2.1**, for example, for $\tan\delta$ less than 0·1, as follows:

$$\tan\delta \approx \tan\delta_e + \tan\delta_h + \tan\delta_r$$

where

$\tan\delta_e$ = tangent of loss angle due to eddy current losses only,

$\tan\delta_h$ = tangent of loss angle due to hysteresis losses only, and

$\tan\delta_r$ = tangent of loss angle due to residual losses only.

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*Electrotechnical vocabulary: Part I Fundamental definitions.

4.2.2 *Quality Factor* — The inverse of the tangent of loss angle.

$$Q = \frac{1}{\tan \delta}$$

where

Q = quality factor, and
$\tan \delta$ = tangent of loss angle.

4.3 Measurement and Calculation of Material Constants on Cores

4.3.1 *Losses per Unit Permeability* — Measured on a core of homogeneous magnetic material (preferably a toroid without air gap), the ratio of the tangent of loss angle to the relative initial permeability of the material and equal to:

$$\frac{\tan \delta}{\mu_i} = \frac{\mu''_s}{(\mu'_s)^2} = \frac{R_s}{\mu_i \omega L_s}$$

Alternatively, the product of relative initial permeability and quality factor may be used:

$$\mu_i Q = \frac{\mu_i}{\tan \delta}$$

where

$\tan \delta$ = tangent of loss angle;
μ_i = relative initial permeability, taken as equal to the toroidal permeability (*see* **3.2.1**);
μ'_s and μ''_s = real and imaginary components of the complex permeability expressed in series terms;
R_s = resistance of the measuring coil in ohms calculated as series resistance, due to the losses in the core only;
ω = 2π × measuring frequency in cycles per second;
L_s = self-inductance of the measuring coil on the core in henrys calculated as series inductance; and
Q = quality factor.

NOTE — The value of $\frac{\tan \delta}{\mu_e}$ at low flux density is independent of the air gap length as long as the leakage remains negligible.

$$\left(\frac{\tan \delta}{\mu_e}\right) \text{core with air gap} = \left(\frac{\tan \delta}{\mu_i}\right) \text{core without air gap}$$

where

μ_e = relative effective permeability at low flux density.

4.3.2 *Hysteresis Material Constant* — Under stated conditions, and in the Rayleigh region, the quotient of the tangent of loss angle due to hysteresis and product of unit permeability and the peak value of the flux density.

$$\eta_b = \frac{\tan \delta_h}{\mu_e B_{max}}$$

where

η_b = hysteresis material constant (in T^{-1}),

$\tan \delta_h$ = tangent of loss angle due to hysteresis only,

μ_e = relative effective permeability, and

B_{max} = peak value of flux density in tesla in the core during measurement.

4.3.3 *Hysteresis Core Constant* — Under stated conditions and within the Rayleigh region, the quotient of the tangent of loss angle due to hysteresis and the product of current and square root of inductance of the measuring coil.

$$\eta_i = \frac{\tan \delta_h}{I_{max} \sqrt{L}}$$

where

η_i = hysteresis core constant (in $J^{-\frac{1}{2}}$),

$\tan \delta_h$ = tangent of loss angle due to hysteresis only,

I_{max} = peak value of the current in amperes passed through the measuring coil, and

L = self-inductance in henrys of the measuring coil placed on the core.

NOTE 1 — The hysteresis core constant η_i and the hysteresis material constant η_B are related as follows:

$$\eta_i = \eta_B \sqrt{\frac{\mu_0 \mu_e^3}{V_e}}$$

where

V_e=effective volume of the core.

NOTE 2 — For the purpose of this standard, the Rayleigh region is defined as the condition prevailing in a ferromagnetic body placed in a periodically varying magnetic field, when the peak value of the field strength is so small that the flux density is described as a quadratic function of the field strength.

$$\frac{B}{\mu_0} = (\mu_i + \delta H_{max}) H \pm \frac{\delta}{2} (H^2_{max} - H^2)$$

where

B = instantaneous value of flux density in tesla,

μ_0 = absolute permeability of vacuum in henrys per metre,
μ_i = relative initial permeability,
δ = permeability rise factor in metres per ampere,
H_{max} = peak value of field strength in amperes per metre, and
H = instantaneous value of field strength in amperes per metre.

4.3.4 *Losses at High Flux Density* — Under stated conditions, the total losses of a core expressed in watts.

NOTE — The total losses of a core may also be expressed in watts at low value of the flux density.

5. VARIABILITY

5.1 Dependence on Temperature — Attention shall be paid, when carrying out measurements of the temperature dependence of the permeability, to irreversible phenomena which are superposed on the reversible ones. The way of avoiding these parasitic effects will be stated after further consideration, but it is important to keep in mind that all definitions in this clause apply only for reversible effects.

5.1.1 *Temperature Coefficient* [*See also* **14.32** *of IS : 1885 (Part I)-1961**]

a) Between two given temperatures (mean coefficient), the relative variation of the quantity considered, divided by the difference in temperature producing it.

b) At a given temperature, the limiting value of the mean coefficient when the difference in temperature is very small.

5.1.2 *Tolerance Over the Temperature Range* — The difference of the limits between which the measured value of the quantity shall lie at any temperature within the specified temperature range, when measured under conditions of temperature equilibrium and under stated conditions of measurement.

5.1.3 *Temperature Factor of the Permeability or a Derived Quantity* — The factor defined by:

$$\frac{\triangle \mu}{\triangle T} \times \frac{1}{\mu^2}$$

where

$\triangle \mu$ = change of the permeability or the derived quantity corresponding to $\triangle T$,
$\triangle T$ = change of temperature, and
μ = permeability (or derived quantity) at a specified temperature.

5.1.4 *Curie Point* — The critical temperature above which a ferromagnetic body is paramagnetic [*see also* **10.5** *and* **10.39** of IS : 1885 (Part I)-1961*].

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*Electrotechnical vocabulary: Part I Fundamental definitions.

5.2 Disaccommodation — The relative variation with time of the initial permeability (*see* **3.1.6**) after complete demagnetization and during storage, free of magnetic, mechanical and thermal disturbance at stated temperature. It is normally expressed as a percentage of the value measured a short time after the demagnetization.

$$D = \frac{\mu_1 - \mu_2}{\mu_1} \times 100$$

where

D = disaccommodation in percent,

μ_1 = initial permeability measured at a given (short) interval after complete demagnetization, and

μ_2 = initial permeability measured at a given (longer) interval after the first measurement.

NOTE — Specific values of temperature and duration are under consideration.

5.2.1 *Disaccommodation Factor* — The factor is defined by:

$$DF = \frac{\mu_1 - \mu_2}{\log_{10} \frac{t_2}{t_1}} \; \frac{1}{\mu_1^2}$$

where

DF = disaccommodation factor,

μ_1 = initial permeability measured t_1 seconds after complete demagnetization, and

μ_2 = initial permeability measured t_2 seconds after complete demagnetization.

NOTE 1 — The permeability is approximately linear with the logarithm of time.

NOTE 2 — The values of t_1 and t_2 are under consideration.

5.3 Instability — The phenomenon of change of permeability caused by an applied disturbance [for example, the difference in initial permeability (*see* **3.1.6**)], caused by a specified disturbance (for example, mechanical, magnetic or thermal) applied to the material.

It is normally expressed as a percentage of the value measured before the disturbance.

$$I = \frac{\mu_2 - \mu_1}{\mu_1} \times 100$$

where

I = instability as a percentage of μ_1,

μ_1 = initial permeability measured before the applied disturbance, and

μ_2 = initial permeability measured after the applied disturbance.

5.4 Instability Factor — The ratio of the instability to the initial permeability measured before the disturbance.

$$IF = \frac{\mu_2 - \mu_1}{\mu_1^2}$$

where

IF = instability factor,

μ_1 = initial permeability measured before the applied disturbance, and

μ_2 = initial permeability measured after the applied disturbance.

6. MAGNETOSTRICTION

6.1 Magnetostriction — The phenomenon of elastic deformation which accompanies magnetization [*see also* **10.34** of IS : 1885 (Part I)-1961*].

6.2 Longitudinal Magnetostriction — Under stated conditions, the relative change of length of a body of ferromagnetic material in the direction of magnetization, when the magnetization of that body is increased from zero to a specified value (usually saturation).

$$\lambda = \frac{\Delta l}{l}$$

where

λ = longitudinal magnetostriction, and

Δl = change of length l measured in the direction of magnetization.

6.3 Transverse Magnetostriction — Under stated conditions, the relative change of length of a body of ferromagnetic material in a specified direction perpendicular to the magnetization, when the magnetization of that body is increased from zero to a specified value (usually saturation).

$$\sigma = \frac{\Delta s}{s}$$

where

σ = transverse magnetostriction, and

Δs = change of length s perpendicular to the direction of magnetization.

6.4 Volume Magnetostriction — Under stated conditions, the relative change of the volume of a body of ferromagnetic material when the magnetization of that body is increased from zero to a specified value (usually saturation).

---

*Electrotechnical vocabulary : Part I Fundamental definitions.

6.5 Reversible Magnetostriction — Under consideration.

6.6 Dynamic Magnetostriction — Under consideration.

7. MISCELLANEOUS

7.1 DC Resistivity — Under stated conditions, the resistance measured by means of direct voltage of a body of ferromagnetic material having a constant cross-sectional area, multiplied by that cross-sectional area and divided by its length.

APPENDIX A

(Note under Clause 2.2*)*

FERROMAGNETIC MATERIAL CLASSIFICATION

A-1. The following material classification has been made on a functional basis :

a) Material principally intended to increase the permeability of a magnetic circuit;

b) Material intended for use in permanent magnets;

c) Material the use of which is based on the rectangular characteristic of the hysteresis loop (data storage);

d) Material intended for use in those cases where special use is made of non-linearity (magnetic amplifiers, switching);

e) Material intended for use in those cases where special use is made of gyromagnetic effects (Faraday-rotation, resonance isolator, non-reciprocal phase shift, field displacement);

f) Material intended for use in those cases where special use is made of magnetostriction (transducers); and

g) Material intended for use in parametric amplifiers.

INDEX

NOTE — This index has been prepared in accordance with IS : 1275-1958*. Index numbers are clause numbers.

irt=in relation to

A

- Absolute permeability 3.1.1
- Amplitude permeability 3.1.7
  - Maximum 3.1.7.2
- Apparent permeability 3.2.3

C

- Circularly polarized fields,
  - Scalar permeability for 3.2.8
- Complex permeability 3.1.5
  - expressed in
    - parallel terms 3.2.5
    - series terms 3.2.4
- Core constant, Hysteresis 4.3.3
- Curie point 5.1.4
- Current losses, Eddy 4.1.2

D

- DC resistivity 7.1
- Dependence on temperature 5.1
- Differential permeability 3.1.10
- Disaccommodation 5.2
  - factor 5.2.1
- Dynamic magnetostriction 6.6

E

- Eddy
  - (Foucault) currents 4.1.2.1
  - current losses 4.1.2
- Effective
  - permeability 3.2.2
  - scalar permeability for plane waves 3.2.9
- Expression of losses 4.2

F

- Factor
  - Disaccommodation 5.2.1
  - Inductance 3.3.2
  - Instability 5.4
  - Quality 4.2.2
  - Temperature, of the permeability 5.1.3
  - Turns 3.3.1
- Ferrimagnetic material 2.4
- Ferrimagnetism 2.3
- Ferromagnetic
  - material 2.2
  - part, total losses of 4.1.1
- Ferromagnetism 2.1

G

- General definition of
  - amplitude permeability 3.1.7
  - losses 4.1
- Gyromagnetic resonance losses 4.1.5

H

- High flux density, Losses at 4.3.4
- Hysteresis
  - core constant 4.3.3
  - losses 4.1.3
  - Magnetic 4.1.3.1
  - material constant 4.3.2

I

- Incremental permeability 3.1.8
- Inductance factor 3.3.2
- Initial permeability 3.1.6
- Instability 5.3
  - factor 5.4

L

- Longitudinal magnetostriction 6.2
- Loss angle, Tangent of 4.2.1
- Losses 4
  - at high flux density 4.3.4
  - Eddy current 4.1.2
  - Expression of 4.2
  - ferromagnetic part, Total 4.1.1
  - Gyromagnetic resonance 4.1.5
  - Hysteresis 4.1.3
  - per unit permeability 4.3.1
  - Residual 4.1.4

M

- Magnetic hysteresis 4.1.3.1
- Magnetostriction
  - definition 6.1
  - Dynamic 6.6

---

*Rules for making alphabetical indexes.

  Longitudinal 6.2
  Reversible 6.5
  Transverse 6.3
  Volume 6.4
Material
  constant, Hysteresis 4.3.2
  constants 3.1
    on components, Measurement and calculation of 3.2
    on cores, Measurement and calculation of 4.3
  Ferrimagnetic 2.4
  Ferromagnetic 2.2
Maximum amplitude permeability 3.1.7.2
Measurement and calculation of material constant on components 3.2
  on cores 4.3

P

Permeability 3
  Absolute 3.1.1
  Amplitude 3.1.7
  Apparent 3.2.3
  Complex 3.1.5
    expressed in
      parallel terms 3.2.5
      series terms 3.2.4
  Differential 3.1.10
  Effective 3.2.2
    scalar, for plane waves 3.2.9
  Incremental 3.1.8
  Initial 3.1.6
  Maximum amplitude 3.1.7.2
  Reversible 3.1.9
  rise factor 3.1.7.1
  Scalar, for circularly polarized fields 3.2.8
  Temperature factor 5.1.3
  Tensor
    irt
    Material constants 3.1.3
    Measurement and calculation of material constant 3.2.6
  Toroidal 3.2.1
Plane waves, effective scalar permeability 3.2.9
Polder's tensor permeability 3.1.4
  irt
    Material constant 3.1.4
    Measurement and calculation of material constants 3.2.7
Practical quantities related to permeability for coils on cores 3.3

Q

Quality factor 4.2.2

R

Relative permeability 3.1.2
Residual losses 4.1.4
Resistivity, dc 7.1
Reversible magnetostriction 6.5
Rise factor, Permeability 3.1.7.1

S

Scalar permeability
  for circularly polarized fields 3.2.8
  for plane waves, Effective 3.2.9

T

Tangent of loss angle 4.2.1
Temperature
  coefficient 5.1.1
  Dependence on 5.1
  factor of the permeability 5.1.3
Tensor permeability 3.1.3
  irt
    Material constant 3.1.3
    Measurement and calculation of material constants 3.2.6
  Polder's 3.1.4
    irt
      Material constant 3.1.4
      Measurement and calculation of material constants 3.2.7
Tolerance over the temperature range 5.1.2
Toroidal permeability 3.2.1
Total losses of a ferromagnetic part 4.1.1
Transverse magnetostriction 6.3
Turns factor 3.3.1

U

Unit permeability loss 4.3.1

V

Variability 5
Volume magnetostriction 6.4

INDIAN STANDARDS

ON

ELECTROTECHNICAL VOCABULARY

IS:	
1885	Electrotechnical vocabulary:
1885	(Part I)-1961 Fundamental definitions
1885	(Part III/Sec 1)-1965 Acoustics, Section 1 Physical acoustics
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1885	(Part IV/Sec 2)-1965 Electron tubes, Section 2 X-ray tubes (*first revision*)
1885	(Part IV/Sec 3)-1970 Electron tubes, Section 3 Microwave tubes
1885	(Part IV/Sec 4)-1970 Electron tubes, Section 4 Cathode-ray tubes
1885	(Part IV/Sec 5)-1972 Electron tubes, Section 5 Pulse terms
1885	(Part IV/Sec 6)-1972 Electron tubes, Section 6 Noise in microwave tubes
1885	(Part IV/Sec 7)-1973 Electron tubes, Section 7 Camera tubes
1885	(Part IV/Sec 8)-1973 Electron tubes, Section 8 Photosensitive devices
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1885	(Part VI)-1965 Printed circuits
1885	(Part VII/Sec 1)-1970 Semiconductor devices, Section 1 General
1855	(Part VII/Sec 2)-1970 Semiconductor devices, Section 2 Diodes
1885	(Part VII/Sec 3)-1970 Semiconductor devices, Section 3 Transistors
1885	(Part VII/Sec 4)-1969 Semiconductor devices, Section 4 Thyristors
1885	(Part VII/Sec 5)-1971 Semiconductor devices, Section 5 Integrated circuits and microelectronics
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1885	(Part XXVI)-1968 Telecommunication relays
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1885 (Part XXXIII)-1972 Piezo-electric filters
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1885 (Part XXXV)-1973 Rotating Machines
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PART XII FERROMAGNETIC OXIDE MATERIALS

Alterations

(*First cover, Pages* 1 *and* 3, *title*) — Substitute the following for the existing title:

'*Indian Standard*

ELECTROTECHNICAL VOCABULARY

PART XII FERRIMAGNETIC OXIDE MATERIALS'

(*Text*) — Substitute 'Ferrimagnetic' for 'Ferromagnetic' wherever it appears in the standard.

(*Page* 5, *clause* **3.1.3**) — Substitute the following for the existing clause:

'**3.1.3** *Tensor Permeability* — The tensor giving the relation between the space vectors representing flux density and field strength inside the material:

$$\vec{B} = \mu_0 (\mu) \quad \vec{H}$$

where

$$(\mu) = \left\{ \begin{matrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{matrix} \right\}$$

is the tensor permeability and μ_{ij} are the tensor permeability components in the general case.'

(*Page* 5, *clause* **3.1.4**) — Substitute the following for the existing clause:

'**3.1.4** *Tensor Permeability for a Magnetostatically Saturated Medium* (*Polder's Tensor Permeability*) — The tensor permeability in the presence of a static magnetic field which saturates the material.'

(*Page* 12, *clause* **3.2.6**) — Substitute the following for the existing clause:

"**3.2.6** *Tensor Permeability for a Magnetostatically Saturated Medium* (*Polder's Tensor Permeability*) — The tensor permeability for a medium, magnetostatically saturated in the z-direction, may be represented by the tensor frequently referred to as Polder's permeability tensor:

$$(\mu)_P = \begin{Bmatrix} \mu & -jx & 0 \\ jx & \mu & 0 \\ 0 & 0 & 1 \end{Bmatrix}$$

where μ and x are the complex tensor components:

$$\mu = \mu' - j\mu''$$
$$x = x' - jx''$$

NOTE 1 — The complex tensor components may be computed utilizing phenomenological descriptions of the dynamic behaviour of gyromagnetic media. The high-frequency magnetic field components are assumed to be small compared to the static ones.

From the Landau-lifshitz equation the following expressions is obtained:

$$\mu' = 1 - \frac{f_0 f_m [f^2(1-a^2) - f_0^2(1+a^2)]}{[f^2 - f_0^2(1+a^2)]^2 + 4a^2 f^2 f_0^2}$$

$$\mu'' = \frac{a f f_m [f^2 + f_0^2(1+a^2)]}{[f^2 - f_0^2(1+a^2)]^2 + 4a^2 f^2 f_0^2}$$

$$x' = \frac{f f_m [f^2 - f_0^2(1+a^2)]}{[f^2 - f_0^2(1+a^2)]^2 + 4a^2 f^2 f_0^2}$$

$$x'' = \frac{2 a f^2 f_0 f_m}{[f^2 - f_0^2(1+a^2)]^2 + 4a^2 f^2 f_0^2}$$

where

$$a = \frac{\Delta H}{2H_0};\ f_0 = \frac{\gamma \mu_0 H_0}{2\pi};\ f_m = \frac{\gamma \mu_0 M_0}{2\pi}$$

and

f = the operating frequency in Hz,

ΔH = the gyromagnetic resonance linewidth in A/m (*see* Note **4.1.5**),

H_0 = the effective internal static field strength in A/m,

M_0 = the saturation magnetization in A/m,

$\mu_0 = 4\pi \times 10^{-7}$ H/m, and

$\gamma = 88\ g \times 10^{-9}$ m²/V s² (for g the effective Lande' factor of the material should be used).

The corresponding Block-Bloombergen expressions are obtained by the substitution:

$$a = \frac{1}{2 \pi f_0 \tau}$$

where τ is the relaxation time.

If losses are neglected, the parameter 'a' vanishes and the tensor components become real and equal to:

$$\mu = 1 - \frac{f_0 f_m}{f^2 - f_0^2}$$

NOTE 2 — The effective internal static field strength, H_0, may under certain conditions be calculated for general magnetically saturated ellipsoids as:

$$H_0 = \sqrt{[H_z + (N_x - N_z) M_0] [H_z + (N_y - N_z) M_0]}$$

where

H_z = the externally applied static field strength (in the z-direction),

M_0 = the saturation magnetization, and

N_x, N_y, N_z = the demagnetizing factors in the three coordinate directions.

This formula does not include the effects of anisotropy fields inside the material.

NOTE 3 — The tensor components may be measured with the aid of cavity perturbation techniques, provided the conditions are specified. The sample, usually in the form of a small polished sphere, is placed in a cavity resonator and simultaneously subjected to a high frequency and a static magnetic field. The tensor components may be calculated from observed changes in the resonant frequency and the quality factor (Q) of the cavity, with the aid of perturbation theory."

(*Page* 12, *clause* 3.2.7) — Delete and renumber the subsequent clauses accordingly.

[*Page* 13, *clause* 3.2.8 (*renumbered* as 3.2.7)] — Substitute the following for the existing clause:

'3.2.7 *Scalar Permeability for Circularly Polarized Fields* — In a medium, magnetostatically saturated in the z-direction, the complex scalar permeability for an electromagnetic wave having a circularly polarized H-field component in a plane perpendicular to the applied magnetostatic field:

$$\mu + = \mu + x$$
$$\mu - = \mu - x$$

where μ and x are the complex components of the tensor permeability for a magnetostatically saturated medium.

NOTE — The subscripts have been chosen in accordance with the signs in the right hand members of the mathematical expressions given above. In practice $\mu +$ is applicable where the H-field component rotates counter-clockwise as a function of time when seen in the direction of the applied static magnetic field. For the opposite sense of rotation, $\mu -$ is valid.'

[*Page* 13, *clause* 3.2.9 (*renumbered* as 3.2.8)] — Substitute the following for the existing clause:

'3.2.8 *Effective Scalar Permeability for Plane Waves* — In a medium, magnetostatically saturated in the z-direction, the complex scalar permeability for a plane electromagnetic wave propagating in a direction perpendicular to the magnetostatic field and whose H-field component is also perpendicular to the magnetostatic field:

$$\mu \perp = \frac{\mu^2 - x^2}{\mu}$$

where μ and x are the complex components of the tensor permeability for a magnetostatically saturated medium.'

(*Page* 14, *clause* 4.1.5, *Note*) — Substitute the following for the existing note:

'NOTE — A measure of the gyromagnetic resonance loss properties of a given material at a given frequency is given by the gyromagnetic resonance line width, *H*, measured on the material at that particular frequency. The gyromagnetic resonance line width is described as the difference between the two magnetostatic field strengths where the imaginary part of any of the components of the permeability tensor for a magnetostatically saturated medium or a linear combination thereof has half its maximum value.'

[*Page* 20, *clause* A-1, *items* (e) and (g)] — Substitute the following for the existing items:

'e) Material, intended for use in those cases where use is made of gyromagnetic effects (Faraday effect, gyromagnetic resonances, permeability variations in the presence of a second magnetic field, etc);

g) Materials for miscellaneous applications (for example, electromagnetic absorbers).'

(ETDC 13)

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